

Comparison of Parallaxes from Eclipsing Binaries Method with Hipparcos Parallaxes

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ABSTRACT

The parallaxes determined by Lacy (1979) by means of eclipsing binaries method are compared with the Hipparcos parallaxes for 19 systems. The residual scatter of the distance moduli inferred from eclipsing binaries method – after allowing for known errors as given by Lacy and Hipparcos – is equal to 0.18 mag. It decreases to 0.08 mag when obviously not fitting semi-detached systems and systems with chromospheric activity of components are removed from the sample.

binaries: eclipsing – Stars: distances

The parallax determination by means of double-line eclipsing binaries is now considered to be one of the most promising methods of distance determination (*e.g.*, Paczyński 1997, see also Kruszewski and Semeniuk 1999 for a historical review). However, before using eclipsing binaries as unquestionable standard candles there is a need to check the accuracy of distances obtained in this way by comparing them with the distances determined with other methods, particularly with the distances from trigonometric parallaxes. The *Hipparcos Catalogue* (ESA 1997) provides us with trigonometric parallaxes for several hundred eclipsing binaries. Popper (1998) used the Hipparcos data as a check of the eclipsing binaries method. Based on known solutions of photometric and spectroscopic orbits he calculated surface brightness of 14 detached eclipsing binaries closer than 125 pc and with the Hipparcos parallax error not greater than 10%. The sample was generally not homogeneous. Six of the fourteen systems had chromospherically active or intrinsically variable components. The $(B - V)$ color indices were taken from different sources and some were uncertain. Popper compared the surface brightnesses of these 14 stars with the calibrated by him (Popper 1980) relation between surface brightness and $(B - V)$ color index. The comparison indicated some deviations from this relation. In particular the early type stars, with $(B - V)$ less than 0.04, were located slightly above the relation, while almost all chromospherically active later type stars were situated beneath the relation, generally more than the typical uncertainty of the surface brightness determination. As suggested by Popper the surface brightnesses of the latter stars were depressed due to spots on their surfaces. The Popper general conclusion was that the relation between surface-brightness and $(B - V)$ color index for the stars of lower temperature was poorly established. Recently

Oblak and Kurpińska-Winiarska (2000) compared the Hipparcos parallaxes with photometric parallaxes calculated for the eclipsing binaries by Brancewicz and Dworak (1980), and revised by Jacob (1999). They were aware of crudeness of the photometric parallaxes obtained from the mass-luminosity relation instead of double-lined spectroscopic orbits, as well as of inhomogeneity of their rich (338 systems in total) sample. They found that for the majority of Brancewicz and Dworak (1980) eclipsing binaries the photometric parallaxes were comparable with Hipparcos parallaxes and that for 103 stars with well determined Hipparcos parallaxes the mean error of the absolute magnitude differences derived from Hipparcos and given by Brancewicz and Dworak is less than 1 mag. The paper showed that the photometric parallaxes as determined by Brancewicz and Dworak could be used as approximate distance determination but are not good for accurate distance determination. There is, however, in the literature a sample which seems to be more suitable for verification of usefulness of the eclipsing binaries method for distance determination than the samples of Popper or of Dworak and Brancewicz. This is a homogeneous sample prepared by Lacy (1979).

Lacy (1979) using the Barnes–Evans (1976) method determined distance moduli $m - M = V_0 - M_V$ for 47 eclipsing binaries with known absolute dimensions based on double-lined spectroscopic orbits. The relevant equation he used was

$$M_V = 42.362 - 5 \log R/R_\odot - 10 F_V(V - R) \quad (1)$$

where the visual surface brightness parameter $F_V(V - R)$ was taken from the surface brightness – color relation as given by Barnes, Evans and Parsons (1976). The homogeneity of the Lacy’s sample is secured by homogeneously determined – from the author’s observations – $(V - R)$ color indices and interstellar reddening. This is important because systematic errors in colors are dangerous, especially when they are different for different objects.

To check the accuracy of this method of distance determination we have compared the distances determined by Lacy with the distances obtained by the trigonometric parallax method from the *Hipparcos Catalogue* (ESA 1997). From the Lacy’s sample of 47 eclipsing binaries we selected 19 EA-type systems with the Hipparcos parallax error less than 20%. All but one (CM Lac) stars turned out to be closer than 200 pc. These stars are listed in Table 1. The variability and the spectral types in columns 3 and 4 of the Table are taken from the *Hipparcos Catalogue*. The dereddened $(V - R)_0$ colors in column 5 are calculated from Lacy’s (1979) data. Column 6 contains the difference $\Delta(m - M)$ of the Lacy’s and Hipparcos distance moduli. Columns 7, 8, 9 and 10 give the Lacy’s and Hipparcos parallaxes and their standard errors. All the values are in milliarcseconds (mas). The Lacy’s parallax errors in column 8 were calculated from the formula

$$\sigma_{m-M} = 5\sigma_\pi \pi \log_{10} e \quad (2)$$

where the distance modulus error σ_{m-M} was taken to be 0.15 mag for OB spectral type stars and 0.11 mag for later spectral type stars, as given by Lacy (1979).

Table 1
Nearby Eclipsing Binaries with parallaxes determined by Lacy and Hipparcos

Name	HIP Number	Var type	Spectral type	$(V-R)_0$	$\Delta(m-M)$	π_{Lacy} [mas]	σ_{Lacy} [mas]	π_{Hip} [mas]	σ_{Hip} [mas]
WW Aur	31173	EA/DM	A3m+A3m	0.146	0.10	11.32	0.57	11.86	1.06
AR Aur	24740	EA	B9.5V	0.009	0.23	7.38	0.37	8.20	0.78
β Aur	28360	EA	A2V	0.077	-0.34	46.56	2.36	39.72	0.78
ZZ Boo	68064	EA/DM	F2V	0.339	0.10	8.47	0.43	8.88	0.78
EI Cep	106024	EA/DM	F2V	0.200	0.09	4.83	0.24	5.03	0.56
V1143 Cyg	96620	EA/DM	F6Vasv	0.407	0.08	24.21	1.23	25.12	0.56
Z Her	87965	EA/AR	F6V	0.540	-0.59	13.37	0.68	10.17	0.84
TX Her	84670	EA/DM	A9V	0.269	-0.14	5.92	0.30	5.55	0.84
V624 Her	86809	EA	A3m	0.138	-0.12	7.31	0.37	6.93	0.74
HS Hya	50966	EA/D	F5V	0.414	0.42	9.08	0.46	11.04	0.88
CM Lac	108606	EA/DM	A2V	0.163	-0.45	5.42	0.27	4.40	0.84
UV Leo	52066	EA/DW	G0V	0.579	-0.20	11.91	0.60	10.85	1.16
δ Lib	73473	EA/SD	B9.5V	0.080	0.67	7.87	0.40	10.72	0.91
RR Lyn	30651	EA/DM	A3m	0.192	-0.02	12.13	0.61	12.01	0.97
U Oph	84500	EA/DM	B5Vnn	-0.086	0.63	4.02	0.20	5.38	0.83
WZ Oph	83719	EA/DM	F8V	0.499	0.34	6.82	0.35	7.99	1.37
β Per	14576	EA/SD	B8V	0.016	0.17	32.51	1.65	35.14	0.90
CD Tau	24663	EA/D	F7V	0.431	0.04	13.43	0.68	13.66	1.64
BH Vir	68258	EA/DW	F8V	0.543	0.14	7.45	0.68	7.94	1.50

Fig. 1 compares Hipparcos parallaxes *vs.* Lacy’s parallaxes. The Lacy’s and Hipparcos parallax errors are also plotted. The most deviating star is β Aur, which is also the star with the largest parallax.

Fig. 1. The Hipparcos parallaxes plotted *vs.* Lacy’s parallaxes together with their standard errors. The closest and the most deviating star is β Aur.

Based on the values of column 6 we have calculated the value of variance for the difference of Lacy’s and Hipparcos distance moduli. This value is equal to 0.1093 what gives 0.33 mag for the standard deviation of this difference. Having the Hipparcos parallax errors (column 10) we could estimate how much they contribute to this value. The errors of the Hipparcos distance moduli of individual stars, calculated with Eq. (2), give 0.0623 for the corresponding variance, so the variance resulting from the Lacy’s distance moduli only is 0.0470, what gives for the standard deviation the value equal to 0.22 mag. The situation improves significantly if we reject from our table the semi-detached systems and the stars with the chromospheric activity of components. There are five such systems in our sample, two semi-detached systems (δ Lib, β Per) and three binaries with chromospherically active components (Z Her, UV Leo, BH Vir). After rejecting these stars we obtain 0.14 mag as the standard deviation corresponding to the Lacy’s distance moduli for the 14 remaining systems. With the

observational standard errors of the Lacy's distance moduli (0.15 mag for OB stars and 0.11 mag for later types), dominated by errors in absolute dimensions of the stars, we can remove their contribution from the corresponding variance of the distance moduli. The resulting difference gives 0.08 mag, as a residual scatter, for the 14 detached systems. For the full sample of 19 systems this residual scatter is equal to 0.18 mag.

Fig. 2. The relation between the difference of the Lacy's and Hipparcos distance moduli and the color index $(V - R)_0$. The error bars correspond to the total error of the difference resulting from the Lacy's and Hipparcos standard errors. The dots denote the detached systems without observed chromospheric activity, the open circles correspond to the semi-detached systems (δ Lib and β Per) or systems with a chromospheric activity (Z Her, UV Leo and BH Vir). The line segments plotted in the figure are obtained with the least square method for the dots only.

Fig. 2 gives the dependence of the Lacy's and Hipparcos distance moduli difference on the color index $(V - R)_0$, together with the total error of the difference resulting both from the Hipparcos and Lacy's determination errors. The open circles denote the semi-detached systems and the chromospherically active stars. If we confine our consideration to the detached systems without chromospheric activity (dots) we see that the dependence between the distance modulus difference and the color index could be described by two linear relations with different slopes. The lines in Fig. 2 were obtained with the least square method. The slope changes at approximately $(V - R)_0 = 0.07$. For the stars with redder colors the distance moduli difference grows with the color what means that the Lacy's distance modulus becomes greater than the Hipparcos distance modulus. The opposite seems to be true for the stars with colors less than 0.07 mag. We suggest that this change of slope in the relation presented in Fig. 2 is related to the change of slope in the relation between the surface brightness parameter F_V and $(V - R)_0$ as given by Barnes, Evans and Parsons (1976). It should be mentioned here that all the standard deviations calculated in the preceding paragraph do not take into account this change of slope of the relation visible in Fig. 2.

The star that lies almost exactly on the intersection of the two line segments in Fig. 2 is β Aur. Perhaps this circumstance explains partly its most deviating location in Fig. 1. Also the fact that β Aur has very shallow eclipses – their depths are equal to only 0.08 mag – could explain the apparent deviation.

In conclusion we can state that the test performed on the data of the Lacy's (1979) sample does not contradict the usefulness of the eclipsing binaries method for the distance determination. The results of our analysis are consistent with the conjecture that the residual scatter of the distance modulus obtained in this way – after allowing both for the Lacy's and Hipparcos observational errors – is less than 0.1 mag provided that we reject semi-detached and chromospherically active systems. This rejection could be made without difficulties, as we have precise criteria for selecting these stars. These are the variability between minima for the chromospherically active systems and the results of photometric orbit solution for the semi-detached systems. It is hoped that this residual scat-

ter will be reduced in the future as the observational errors are reduced, and the modeling of eclipsing binaries improves. Here we should remind, however, that the Lacy's sample contains the stars from the Sun vicinity with homogeneous population features. We cannot exclude that the application of this method to the systems with different population characteristics would increase the scatter.

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